A Century of Water Supply to the Western Australian Goldfields and Wheat-belt from Mundaring Weir and the Kalgoorlie Pipeline

Richard G. Hartley

As the Western Australian gold rush gathered momentum in the early 1890s, one of the biggest problems facing gold seekers on the Eastern Goldfields was the lack of adequate water supplies. The Coolgardie region was found to have a very unreliable rainfall, with annual falls during the early 1890s varying from 90 mm to 260 mm. The region lacked any surface supplies of fresh water, and according to geologists, there was little prospect of finding useful artesian supplies there. A variety of short term water supply works were installed by the Public Works Department, including earth dams, catchments on rock outcrops, condensing plants, wells and bores. However, it became increasingly difficult and costly to provide the rapidly expanding population with uncontaminated water supplies by such means. The government was pressed to provide reliable supplies, but the high evaporation rate and lack of suitable dam sites ruled out the development on the goldfields of impounding dams of large enough capacity to store sufficient water to last between the infrequent rains. A source outside the goldfields was needed, and by mid-1895, the Engineer-in-Chief, C.Y. O'Connor, had instructed the Public Works Department to begin preliminary designs for a scheme to pump water from a source in the Darling Range to Coolgardie, a distance of 523 kilometres (325 miles).[1]

Geoffrey Blainey in his book on the history of the Kalgoorlie-Boulder mines, *The Golden Mile,* criticised O'Connor for providing a water supply to the Kalgoorlie region which had a delivery capacity much greater than the water supply requirements of the district's mining industry, which Blainey claimed was 'the main target of the water scheme'.[2] It could be argued that public health was the 'main target' of the scheme. However, the chief flaw in Blainey's argument is that he criticised O'Connor for over-supplying the needs of the mining industry in 1903, when pumped water first arrived in Kalgoorlie, whereas O'Connor had to decide on the delivery capacity of the pipeline fully seven years earlier in 1896. To demonstrate how difficult it would have been to estimate the future water requirements of the goldfields, when O'Connor's team started work on the scheme, one has only to take a quick look at the mining industry on the Eastern Goldfields in October 1895.

Coolgardie was then the undisputed capital of the goldfields and centre of the colony's mining industry. The town had a population of about 8,000, while within a radius of about 40 miles, there was a floating population of another twenty or thirty thousand. 1895 was the first year of the speculative boom in Westralian mining shares on the London stock exchange. Yet earlier in the year the two speculative sensations near Coolgardie, the Londonderry Golden Hole and the Wealth of Nations mine at Dunnsville, had both proved to be practically worthless. Coolgardie's premier mine, Bailey's Reward, which had started the boom, had also failed in April 1895, and other mines in the Coolgardie area were only processing ore intermittently. Most managers claimed that this was due to a shortage of water, but for many mines it was more likely to have been more a shortage of ore. Kalgoorlie was an insanitary village of tents and dust, and Boulder did not even exist. On what was to become the Golden Mile, south of

Kalgoorlie, there were several small ten-head stamp batteries working away almost hidden in woodland. The Great Boulder was the only mine to have done enough exploration to suggest that its ore extended to depth. On the strength of Great Boulder's results, speculative fever in Hannan's stocks was about to take off in London.

In 1895 or 1896, any estimate of the amount of water which mines on the Eastern Goldfields would require in twelve months time would have been a mere guess. Even more difficult would have been any evaluation of requirements in three years time, which was the minimum period needed to build a dam and pipeline. When O'Connor asked the Mines Department to request its wardens to estimate how much water the mines on the Eastern Goldfields would be likely to purchase from a pipeline supply, only one warden replied. His comment was predictable: 'I am unable to give any estimate that would be worth the paper it is written on.' [3]

In 1895, the few small processing plants on the Golden Mile were using in the order of 2,000 gallons of water for every ton of ore crushed. This was a high usage by international standards, which may seem surprising on a field where water was so scarce. However, it was a usage which was necessary because the talc-like nature of the oxidised ore tended to clog stampers, unless washed through with a good flow of water. The extraction rates were also poor because the stamped ore readily formed slimes from which gold could not be easily removed by amalgamation with mercury. Tailings, therefore, had to ponded in dams until such a time as they could be treated effectively.

Water shortages had been anticipated by most of the early mining companies on the Golden Mile. Their managers competed vigorously to obtain water supplies for their mines from a variety of sources. Good cyclonic rains fell in March 1896, which filled Hannan's Lake and other seasonal lakes south of Boulder, and these were utilised by a number of companies until they, and the shallow aquifers below them, dried up through overuse. The Ivanhoe mine was probably the first mine to strike saline ground water in its main shaft, in March 1895. By 1897, several companies were using shaft water to supplement lake sources for some of their processing needs. It was less saline than water from lake sources and, therefore, fewer chemicals were needed for processing the ore.

The adoption of the filter press, in 1897, to contain slimes while gold was removed by cyanide treatment, solved the problem of how to treat slimes, and allowed the recycling of water, with important consequences. By 1900, water usage had fallen dramatically from 2,000 gallons per ton in 1896 to around 500 gallons per ton. In 1903, when water pumped from the Helena River arrived in Kalgoorlie and most mines were processing sulphide ores, the average water usage had fallen even further to between 200 and 300 gallons per ton. The scale of operations on the Golden Mile had also changed dramatically. In 1896, only 33,000 tons of ore were processed in the East Coolgardie Goldfield, but in 1903, when this goldfield had become one of the most productive in the world, 967,000 tons of ore were processed, almost thirty times the 1896 figure. Such dramatic changes in the scale of production and method of water use would have made nonsense of any estimates that could have been made in 1895 or 1896 on future water usage.

If O'Connor did not set the service level of the pipeline from an estimate of future water usage, how did he do it? The evidence points to him having determined it in a more pragmatic manner,

which took into account the construction and operating costs of a pipeline of various capacities and which also allowed for possible pipeline leakage and loss of capacity.

The first, trial designs for a pumped supply, which were completed in November 1895, were based on three different supply rates: one million gallons per day, five million gallons per day and ten million gallons per day.[4] In 1896, the processing requirements for the whole of Western Australia's gold mining industry could have been met with water supplies totaling one million gallons per day - assuming a usage of 2,000 gallons per ton of ore. The emergence of the Eastern Goldfields as the main gold mining district in Western Australia was already becoming evident, and O'Connor argued that a one million gallons per day capacity pipeline would probably only be adequate for short term requirements. Because of its smaller diameter, such a pipeline would have had a friction head nearly twice that of a five million gallons pipeline, and its operating costs would have been greater in the same proportion. O'Connor estimated that a one million gallons capacity pipeline would require about twelve to fifteen pumping stations compared with the eight or nine needed for a five million gallons line.[5]

He also argued that, as the cost of pumping was directly proportional to the quantity pumped, it would be no more expensive to pump a million gallons daily through a pipeline of five million gallons capacity than it would be to pump the same quantity through a one million gallons capacity pipeline. In fact it would be cheaper because of the reduced friction in the larger pipe.

O'Connor estimated that a supply of one million gallons would entail a capital cost of about £1 million, while a five million gallons supply would cost £2.5 million; five times the capacity for 2.5 times the cost. The delivery cost of the smaller capacity scheme - about 66 pence per 1000 gallons - would also be considerably more than the 42 pence estimated for the larger scheme.

What probably made O'Connor opt for a five million gallons capacity pipeline were two factors, which he may have felt he could not afford to air in public before the scheme was approved by parliament. These were the need to allow for likely leakage from the pipeline and its possible loss of capacity due to the deposition of material inside the pipe. The commission of English engineers, which was appointed in January 1897 to advise on pipes and pumping, in its first report, in August 1897, was particularly concerned about leakage.[6]

In order to identify potential dam sites for the scheme, O'Connor's principal assistant, Thomas Hodgson, made an exhaustive examination of the principal Darling Range watersheds and rivers in 1895-96. Of the thirteen potential sites identified, Hodgson was emphatic in recommending one on the Helena River, which he was confident would be capable of providing very economically the required supply of five million gallons per day. Mundaring Weir, which was built at the site, was a hundred feet high, mass concrete dam capable of impounding over 4,600 million gallons.

The steam-driven pumps chosen for the scheme's eight pumping stations were high duty units with performance capacities in excess of the initial requirements. During commissioning trials they were shown to be the most efficient pumps of their type in the world. Today, these attributes help to place the surviving pumps amongst the icons of Australia's industrial heritage. The reasons why they were chosen are intriguing.

The commission of English engineers had an important role in advising on the supply of the pumping machinery. The commission was advised by O'Connor that Collie coal, at an estimated cost of 32 shillings per ton, was to be used to fuel the pumps. In relation to its heating value, Collie coal was a high-cost fuel. The commission, therefore, recommended that high duty machinery be used in order to extract the maximum energy possible from the fuel. O'Connor appears to have been instructed by the Forrest government to use Collie coal in preference to the wood fuel, which at the time, was used almost universally on the goldfields. The decision, which was probably made in early 1896, was undoubtedly a political one. When viewed in terms of the development of the Collie coalfields, it must be considered, at best, to have been an optimistic one. Viewed less favourably, it could be considered foolhardy. Although a 1,000 ton sample of coal had been raised at the Collie government mine for testing in 1893, it was not until 1899 that the first successful commercial production of Collie coal commenced.[7] The scheme pumps operated on coal for less than a year. As soon as it became obvious that the far cheaper, locally cut, firewood fuel would suffice, coal was abandoned in favour of wood.

Originally the government only intended to provide scheme water to service reservoirs, from which local authorities would provide reticulation to users. This arrangement worked in Northam and Southern Cross, but on the Coolgardie and East Coolgardie goldfields the task of reticulation was too extensive for local governments to undertake. Even before the scheme was opened in January 1903, it was clear that the quantity of water required on the goldfields in the short term would be well below the five million gallons per day capacity of the pipeline. A new organisation, the Goldfields Water Supply Administration (GWSA) was set up by the government, under W.C. Reynoldson, one of O'Connor's most able assistant engineers. The task of the GWSA was to manage all aspects of the scheme, including water sales and reticulation. Unofficially, its job was to expedite reticulation and sales to ensure that the government did not make a huge loss in the early days of the scheme's operation. It succeeded in carrying out the reticulation remarkably quickly. By June 1904, services had been provided to residences and commercial premises in 75% of Boulder, 63 % of Kalgoorlie and 40% of Coolgardie.

The eighteen leading mines on the Golden Mile formed the Kalgoorlie and Boulder Mines Water Trust, in 1903, to ensure greater bargaining power in their negotiations with the government over the price at which water was to be sold to them. The mines appeared to be in a position of strength because they could claim to be operating perfectly satisfactorily without the use of scheme water, using saline water for processing purposes. The snags were that the levels of ground water in shafts were being lowered, making it more expensive to pump, while water from lake sources was a diminishing resource, which was also becoming more expensive as the lake sources nearest the mines became exhausted. Moreover, the mine managers knew that they would shortly have to obtain much larger quantities of water for processing. This was because, as the average grade of ore diminished with depth, larger quantities of ore had to be mined and processed to maintain profitability. To obtain economies of scale, the mines had to build very big processing plants, which required increased quantities of water. Use of scheme water offered the mines certainty of future supply. Its use also directly reduced ore treatment costs, for when scheme water was used for processing, fewer chemicals were required than

when saline water was used. Moreover, less plant maintenance and fewer replacements were needed due to reduced metallic corrosion.

In September 1903, the Water Trust came to a compromise agreement with the Government. In return for members of the trust ceasing to use saline water for processing, the Government agreed to sell scheme water to trust members at sixty pence per 1,000 gallons, which was approximately the same price as the cost of saline water.[8] To encourage increased water usage, additional water could be bought by trust members at a reduced rate of eighteen pence per 1,000 gallons, if it were used for liquefying (or 'sluicing') filter press residues so that they could be pumped to slime dumps (a purpose for which saline water was commonly used). The pricing arrangements resulted in substantial cost reductions in the mines' processing costs, although the GWSA initially operated at a loss.

In the first half of 1904, the GWSA provided an average of 1.26 million gallons of water per day to its customers. The water was distributed as follows:

Railway use		18 per cent
Mines at Kalgoorlie-Boulder		55
Mines at Coolgardie, Bonnievale and Burbanks		2
Mines at Southern Cross		1.5
General Services:	Kalgoorlie	12
	Boulder	6
	Coolgardie, Burbanks, Bonnievale	2
	Southern Cross, Northam	1
	Country Districts	2.5
	Total	100 per cent

The quantities of water used in Kalgoorlie gradually increased to an average of 1.59 million gallons per day in 1906-07, and then to 2.20 million gallons in 1910-11.[9]

The GWSA managed the scheme until 1912, when under a reorganisation of government water supply services, the GWSA was abolished and management of the scheme reverted to the Public Works Department. Reynoldson, who had made an invaluable contribution to the construction and operation of the scheme, was not re-employed and went farming.

As waters from winter and spring rains overflowed Mundaring Weir almost every year, it is not surprising that residents of the Perth metropolitan area, who still suffered from a less than adequate water supply system, called for this 'surplus' water to be used for metropolitan supplies. The first water from Mundaring Weir to be supplied to a metropolitan area was provided as early as 1906, when a gravity main was built from Mundaring Weir to service parts of Guildford and Midland Junction.[10] The areas supplied were gradually increased until, by 1913, an average of about 0.7 million gallons were provided daily.[11]

In 1907, the Perth city engineer proposed raising Mundaring Weir to provide further supplies for the metropolitan area. The government set up a technical committee under Reynoldson, chief engineer of the GWSA, and including the Perth and Fremantle municipal engineers, and

William Leslie, former resident engineer during the construction of the weir.[12] As a means of supplying water to the metropolitan area, the majority opinion of the committee preferred the construction of a dam on the Canning River rather than the raising of Mundaring Weir, although Leslie preferred the Mundaring option.

During and shortly after construction of the weir, small scale water seepage through horizontal and vertical cracks in the concrete of the weir had become evident. In 1914, when raising the dam was again considered, in order to determine the extent of this seepage, three vertical bores were drilled through the full height of the wall. The boreholes rapidly filled with water to levels consistent with the existence of an hydraulic gradient through the wall. The concept of seepage water within a dam wall exerting an upthrust on the wall was a concept in dam design which had been developed since the original design of the wall. In 1914, this uptrust was found to have an adverse effect on the stability of the wall, but not to a critical extent.[13] However, it did rule out raising the wall, unless this operation included an improvement in the stability of the wall and also provided for drainage within the wall.

Whilst the scheme was intended to serve the immediate needs of the Eastern Goldfields, the premier of Western Australia during the planning of the scheme, Sir John Forrest, undoubtedly considered that its longer-term future was to service agriculture. From 1907, when the first agricultural branch main was built at Tammin, the GWSA played an increasing role in agricultural development in the central wheat-belt by providing water for stock and domestic use.[14] In 1912 a first ‘comprehensive scheme’ of agricultural extensions from the main pipeline was planned, and over the next thirty years these were pushed out to the hydraulic limits of supply from the pipeline.[15]

By 1914, an average of 3.3 million gallons were being pumped daily from Pumping Station No.1 at Mundaring. One-fifth went to agricultural areas, one-fifth to mining areas in the Yilgarn, and three-fifths to Kalgoorlie-Boulder. Usage had peaked in Kalgoorlie-Boulder in 1910-11 at 2.2 million gallons per day, but this average gradually fell as gold production declined until the industry’s revival in the mid-1930s. In 1911, 1912 and 1913, laterals were built to the mining centres of Bullfinch, Marvel Loch and Westonia, in the Yilgarn Goldfield, which had been the scenes of the last three gold rushes of the pre-war period.[16]

A major problem which preoccupied PWD engineers for over thirty years was leakage from the pipeline caused by internal and external corrosion of the pipes. The problem had been foreseen by the commission of engineers. However, it was, in fact, a far more complex problem than the commission had anticipated, because the corrosion was due to several different factors. External corrosion of the underground pipeline due to adverse soil conditions occurred intermittently along the pipeline, but internal corrosion was a more universal problem.

The first indication of serious internal corrosion was discovered in 1906, when a significant increase was noted in the pumping head, or resistance to flow, at one pumping station. When the whole pipeline was tested it was found that every section of the pipeline had suffered a reduction in carrying capacity of between 12% and 53%. When a number of pipes were removed for examination, the reduction in capacity was found to be due to extensive tuberculation in the form of round, spongy, black tubercles of up to 1.25 inches in diameter,

predominantly consisting of iron oxides, and which formed over pittings in the steel pipe of not more than one eighth of an inch deep. On Reynoldson's recommendation, the government engaged a group of specialist consultants, Sir Alexander Binnie, Son & Deacon, Sir William Ramsay and Mr Otto Hehner, to advise on remedial measures.

The consultants' 1909 report (known as the 'Binnie Report'), concluded that internal corrosion was due to dissolved oxygen contained in the pipeline water which could be removed by spraying the water into a vacuum.[17] It also found that experimental dosage of the reservoir water with lime, by lowering the acidity of the water, appeared to largely prevent corrosion. A board of government engineers and scientists, chaired by Engineer-in-Chief, James Thompson, decided to adopt the lime dosage treatment, and to supplement it later, if necessary, with vacuum deaeration. Other structures along the pipeline, such as summit tanks, were to be provided to minimise aeration of the water in transit.

Lime dosage was carried out from 1910 to 1916, but was found to do little to prevent or arrest corrosion. Moreover, the treatment caused a deposit of calcium carbonate to build up inside the pipes, which substantially reduced their carrying capacity. Lime dosage was, therefore, replaced by a vacuum deaeration process, which commenced in December 1917.[18] The deaeration plant, which was the first of its type in Australia, was designed by the Public Works Department according to guidelines in the Binnie Report, and was installed at No.1 Pumping Station at Mundaring. The deaerators operated very successfully and, in association with the measures taken to minimise the entry of air into water in transit along the pipeline, largely overcame a major cause of internal corrosion.

However, one of the chief sources of continuing leakage was due to corrosion at the joints between pipes. The pipeline consisted of steel pipes, 8.53 metres (28 ft) long and 762 mm (30 in) in diameter, which had been factory-fabricated from two plates formed into semicircles and joined using a locking bar device patented by a Melbourne engineering contractor, Mephan Ferguson. The longitudinal locking bar joints in the pipes performed perfectly in service, but during the 1920s, corrosion at the transverse lead-sealed joints between pipes was a cause of increasing concern. Maintenance costs and water losses, 90% of which occurred at the lead joints, became increasingly serious problems. There was even concern, in 1930, about the department's ability to maintain continuity of supply.[19] In 1929, 307 million gallons or 0.84 million gallons per day, a quarter of the total water leaving Mundaring, were lost en route through leakage.[20]

During the peak summer period, leakages of up to 50% of the total volume leaving Mundaring were recorded on several occasions. In one year alone, 1931-32, there were no less than 14,326 pipe bursts on the pipeline, that is, an average of 39 per day. However, during the peak summer pumping period, the daily average could well have been double that number. Cycle patrols, or 'length runners', patrolled the pipeline during the day, making temporary repairs with wooden wedges.[21] At night, patrols traveled on motor trolleys along the railway, which ran parallel to the pipeline for most of its route, armed with searchlights, to locate any bursts that could cause wash-outs of the railway formation, which might lead to a serious train accident.[22] A measure of the seriousness of the situation was that, in October 1930, Premier Mitchell instructed the

under-treasurer to find money for the refurbishment of the pipeline, despite the State's financial plight caused by the onset of the Depression.[23]

Mitchell's decision to fund investigations into ways of refurbishing the pipeline was soon vindicated by the development by the PWD of a radical, new method of relaying the pipeline above ground. The method was devised by Norman Fernie, GWS district engineer at Northam, and his assistant, Reginald Keating. It involved trimming-off the corroded end sections of the pipes, and replacing the flexible lead joints with rigid welded joints, forming what is known as a 'continuously welded pipeline'.[24] The inside of the pipe was lined manually with a 12.5 mm thick mortar lining to inhibit corrosion and decrease friction. The outside of the pipe was recoated and painted with a sun-reflecting paint. The main reason for O'Connor's decision to lay the pipeline underground had been the large expansion and contraction of the pipeline expected as a result of the high daily range of temperatures experienced by an above ground pipeline, often exceeding 100 degrees Fahrenheit. This range of temperature was greatly reduced by laying the pipeline underground. In the pipeline reconstruction, the temperature-induced forces were provided for by building reinforced concrete anchor-blocks over the pipe at 50 metre intervals. These blocks prevented the movements, and transferred the forces into the ground. This was the first time anywhere in the world that pipe anchorages of this type had been used to permit such a large diameter pipeline to be laid above ground in such adverse conditions. Today, such anchor blocks are familiar features of all above ground pipelines in Australia and in many other parts of the world with equivalent conditions.

The decision to reconstruct the whole pipeline by this method was made in September 1933, after a trial section of the refurbished pipeline had operated successfully for over twelve months in a high pressure section. Because only limited quantities of new steel pipes could be bought due to the Depression, and before quantities of the original locking-bar pipes became available for refurbishing work, pipeline diversions around badly leaking sections in the lower pressure sections were built with pipes made from karri timber staves, assembled like barrels.[25] In the first four years, 63 km of wood stave pipes were installed as a 'temporary measure'. Thirty-two kilometres of these pipes were still in this 'temporary' service in 1963. Much of the reconstruction work on the pipeline, particularly the exposure of the underground pipes, was done as an unemployment relief project. At the peak of activity, in 1934, over 400 men were working on the pipeline, many of them city workers with no previous experience of heavy manual work.

The loss of large quantities of water due to the extensive leakage from the pipeline inhibited the extension of agricultural laterals during the 1920s. The reconstruction of the pipeline during the 1930s gradually reduced losses and enabled larger water quantities to be provided to satisfy increased demand in Kalgoorlie-Boulder due to the revival in mining. A new branch main was also built to Norseman in 1936 to service expanded mining production there.[26]

In 1943-44, the average daily pumping rate from Mundaring exceeded O'Connor's figure of 5 million gallons for the first time.[27] In 1951-52, the year in which the raising of Mundaring Weir was completed, a record daily average of 7.34 million gallons were pumped by the steam pumps. This pumping rate was only achieved by having all three pumps (including the stand-by pump), at both Pumping Station No.1 and Pumping Station No.2, in operation continuously

throughout the summer months, with the sole exception of one 24 hour period of down-time on 5 February 1952. It was a remarkable demonstration of the reliability of the fifty-year-old pumps and of the dedication and skill of their operators. However, it was the last stand of the Mundaring steam pumps, for in the next year,1953, the pumps at both stations were replaced by electrically powered pumps, which were located in a new pumping station close to Pumping Station No.1, and had with a capacity of 15.9 million gallons per day.

The first proposal to provide water to poorly serviced towns and agricultural areas in the Great Southern and Central Wheat-belt (including York, Katanning, Narrogin and Wagin) from Mundaring Weir and other reservoirs in the Darling Range is believed to have been made in 1934 by B.S. Crimp, the PWD hydraulic engineer. Following a recommendation by Director of Works, Edward Tindale, a committee was appointed to consider the matter. It comprised the government's three most senior hydraulic engineers, Crimp, Walter Weller, engineer for the GWS, and Russell Dumas, who was then engineer for Metropolitan Water Supply. The three engineers agreed that the proposal was sound but disagreed on the most suitable reservoir sites from which to service the scheme. Weller and Crimp favoured Mundaring Weir, augmented by a new source at North Dandalup, while Dumas wished to use only Mundaring.

Further work on the scheme was carried out by the PWD under Dumas during the war, and in May 1945, the details of a proposed 'Comprehensive Agricultural Areas and Goldfields Water Supply Scheme' were announced. The headworks were to be provided by the raising of Mundaring Weir and of Wellington Dam on the Collie River. Water was to be reticulated to approximately twelve million acres of agricultural land for stock and domestic use. Half of the water was to be provided by each dam. The existing GWS pipeline was to be upgraded and a new, steel main and pumping stations built to provide reticulation from Wellington Dam to the southern agricultural areas. Raising of the dams would be paid for by the Western Australian government. Commonwealth assistance was sought for the financing of the reticulation. The Commonwealth appointed an expert committee to examine the proposals and an equivalent State body was also formed.

After talks between the two committees, the Western Australian government submitted a revised scheme, the 'Modified Comprehensive Scheme', which was designed to service the priority areas nominated by the Commonwealth committee. The area to be served was reduced to four million acres and the number of towns from 35 to 23. The Great Southern towns, which were most urgently in need of adequate supplies, were to be serviced by Wellington Dam, and the main agricultural area nominated by the Commonwealth, which was north of the GWS pipeline, was to be serviced from Mundaring Weir. Legislation for the revised scheme passed through the State parliament at the end of 1947 and the enabling Commonwealth legislation, which provided for subsidies on a pound-for-pound basis, was passed in 1948.[28]

In 1963 the State government applied to the Commonwealth for further funding to provide water supplies to agricultural areas north of the GWS pipeline, which had been in the original scheme but had not been provided for in the Modified Scheme, and also for some agricultural areas in the Great Southern. This time, interest-bearing loans were provided rather than subsidies, but the State proceeded with the works, which were completed in 1974.[29]

Reticulation to most of the agricultural areas included in the Modified Scheme, which was completed during the 1950s, made a very important boost to the State's economy. The security of water supply, which it provided, enabled farmers to maintain stable flock numbers during a period when wool prices were at an historic high.

Work on the raising of Mundaring Weir had commenced in 1946. The weir was the first major dam to be raised in Australia. Before the new work could commence the seepage paths identified in 1914 had to be sealed. This was carried out by pumping grout into vertical holes drilled at two-metre centres along the top of the weir, each penetrating down the full height of the wall.[30]

The dam structure was raised by ten metres by building up the downstream side of the dam. The main technical difficulty in the works was to provide for the movement of the new concrete relative to the old, while the former was still setting. This was achieved by leaving a one metre wide slot between the new and old work, which was bridged by ribs from the new work. The interfaces between the ribs and old work were lubricated to allow movement. When all movement ceased, the slot was filled with coarse aggregate and the gaps in the aggregate filled by pressure grouting. Several innovative techniques were developed for these operations. Drains were also provided between the new and old works to prevent any further seepage through the old wall penetrating into the new concrete.[31]

Progress on raising the weir was slow because of the shortage of both skilled and unskilled labour, and of all types of construction material and new equipment during the immediate post-war period. In 1948, the labour situation was eased when European war refugees, or 'Displaced Persons', working under the two-year directed labour scheme, were allocated to work on the dam. The Public Works Department was one of the first organisations in Western Australia to employ large numbers of refugees. A total of seventy-three refugees worked at Mundaring and, during the last three years of the project, the majority of workers on the weir were these 'New Australians'.[32]

In addition to the replacement of the steam pumps at No.1 and No.2 Pumping Stations, those at Cunderdin (No.3) and Merredin (No.4) were also replaced, during the 1950s, by electrically driven centrifigal pumps in new pumping stations, as part of the Modified Comprehensive Scheme. Between 1968 and 1970, the last four steam stations at Yerbillon (No.5), Ghooli (No.6), Gilgai (No.7) and Dedari (No.8) were also replaced. An electric station was provided at Yerbillon and another at Ghooli, the latter replacing both Ghooli and Gilgai steam stations. As electrical power was not initially available at Dedari, the new station was provided with diesel-powered pumps until 1984, when the station was converted to electric power.[33]

The phasing out of the steam stations was the end of an era. When fully manned, each station had required a complement of about ten men. The small, self-contained communities formed by these men and their families, some of whom had spent much of their working lives on the pipeline, were dispersed, as the new stations were unmanned or required only caretaker/emergency operators. With the closure of the steam stations in the wheat-belt, from Cunderdin to Ghooli, an important link with the farming community was also broken. In the dark days of the Depression, when so many farmers were forced to walk off their farms, it had

been the contracts for supplying the pumping stations with firewood which had allowed several Italian migrant farmers and their families to survive on their farms despite considerable privation.[34]

The completion of the construction of Canning Dam, in 1940, at last provided the people of Perth with a reliable source of good quality water. Its completion was also providential for the Goldfields Water Supply, for at the end of a very dry winter in 1941, Mundaring Weir reservoir held only 1,058 million gallons, less than a quarter of its capacity. Fortunately it was possible to transfer 100 million gallons from the recently completed Canning Dam to Mundaring Weir, which enabled the GWS to maintain supplies to the goldfields and agricultural areas, although consumption restrictions had to be applied during the 1941-42 summer. A similar situation arose during the 1944-45 summer, when the supply from Mundaring was augmented by 380 million gallons from Canning Dam.[35] During the 1960s, branch mains were built from the raised Mundaring Weir to supply the outer Perth metroplitan areas of Mundaring, Darlington and Kalamunda.[36] To increase the effective storage capacity of Mundaring Weir reservoir, a pipehead dam was built in 1971 on the Lower Helena, below Piesse Brook.[37] Water from this dam was pumped back into Mundaring Weir reservoir. Later the pumping capacity was increased, and the pipeline duplicated.

The main new mining development to be serviced by the scheme during the 1950s was Western Mining Corporation's gold mine at Bullfinch, operated by Great Western Consolidated. An existing spur line from Southern Cross was relaid with larger capacity pipes to provide water for the mine and township. Subsequently, gold mining went into a slow decline. Then, in 1966, with the discovery of nickel at Kambalda, came an urgent request from Western Mining Corporation for a spur line from the Norseman main to provide water for mining and ore processing, and for servicing the company's towns, at East and West Kambalda. Initially, the requirement was for 200,000 gallons per day but this was later increased to two million gallons per day.

To provide for such a large increase in capacity, the PWD had to make a major upgrade of the whole scheme, including additional pumping stations and summit tanks, and the duplication and/or enlargement of various sections of the pipeline. Even the remaining 'temporary' wood stave pipes had to be replaced after thirty years in service. Just as significant was the institution of a new, two-tier, system of charging consumers. Every large consumer using more than 49 kilolitres per day had to pay a headworks contribution based on the consumer's peak demand, plus a delivery charge of about one dollar per kilolitre. Over the five years from 1967 to 1972, Western Mining Corporation is believed to have made headworks contributions totalling about $15 million.[38] Another lateral for mining operations was provided, in 1966, for the BHP subsidiary, Dampier Mining Corporation, to the iron ore mine and township at Koolyanobbing, north-west of Southern Cross.

During the first half of the 1970s there was a gradual reduction in the amount of water used in Kalgoorlie-Boulder as mining production fell to its lowest level in the twentieth century. However, the tide had turned by the end of 1975, and the gradual rise in the gold price heralded a third boom period on the goldfields, the 'long boom' from 1982 to 1997. By the 1990s the quantities of water required for the processing of the huge quantities of low-grade ore being

mined was far in excess of the amounts which could be provided by the Mundaring pipeline. New water strategies had to be devised by the mining companies. These involved the use of hypersaline water for processing purposes and the maintenance of scheme water for potable and specialist uses only. The hypersaline water, which is up to six times as saline as sea water, comes from ancient, underground water courses. These palaeochannels have very low recharge rates and at the present rate of usage will probably last only another ten or fifteen years.[39,40]

The low-grade lateritic nickel and cobalt mines, which are being developed in the Kalgoorlie region, are also using, or are planning to use, for their processing works either hypersaline water, or sea water piped from the Southern Ocean. For their potable requirements, and those of their workforce, they either use Scheme water or desalination plants. The infrastructure of the Goldfields Water Supply Scheme thus still plays a major role in mining and mineral processing on the goldfields, and in the supply of potable water to its residents. In 1996 the pipeline provided an average of 28 megalitres per day (6.2 million gallons per day) to services east of Coolgardie of which 38 per cent was for mining uses (including mineral processing) and 62 per cent for residential and commercial purposes.[41] Compared with 1904, a much larger proportion of the water goes to domestic and commercial users, which indicates the extent to which the mining industry has had to turn to other sources for its requirements.

The construction of the Goldfields Water Supply Scheme has been widely acclaimed as an outstanding engineering achievement. The scheme provided the goldfields with one of the most important requirements for civilised urban life, a reliable water supply. It supplied the requirements of the mining industry, and remarkably, was built at a cost which was very close to O'Connor's estimate made seven years before its completion. The operation of the scheme over nearly a hundred years, including its maintenance, reconstruction, extension and refurbishment, has received far less recognition, yet has involved a series of engineering works which have been every bit as innovative as the original scheme. Moreover, successive generations of engineers and pipeline operators, who have proudly followed in the tradition of service set in O'Connor's era, have adapted the scheme to serve every new industrial and agricultural development in the goldfields and wheat-belt. There is every prospect that the scheme will continue to serve Western Australia for the foreseeable future.

Endnotes

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